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A NEW APPROACH TO TEACHING SIGNAL PROCESSING AT UNDERGRADUATE LEVEL

B. BOASHASH, S. SRIDHARAN and V.CHANDRAN

Signal Processing Research Centre
School of Electrical and Electronic Systems Engineering
Queensland University of Technology
Brisbane, Qld. Australia 4001

ABSTRACT

This paper describes the design and implementation of a unique undergraduate program in signal processing at the Queensland University of Technology (QUT). The criteria that influenced the choice of the subjects and the laboratories developed to support them are presented. A recently established Signal Processing Research Centre (SPRC) has played an important role in the development of the signal processing teaching program. The SPRC also provides training opportunities for postgraduate studies and research.

1. INTRODUCTION

The School of Electrical and Electronic Systems Engineering of Queensland University of Technology was one of the first in Australia to recognise, in the early eighties, the importance of an enhanced signal processing education in the undergraduate curriculum. It now offers three bachelor degrees in electrical and computer engineering – a single degree, a double degree in combination with information technology and an aerospace avionics degree. All these courses have a strong signal processing content. A newly established Signal Processing Research Centre has played an important role in the development of the signal processing units in these courses. It was possible to conduct an advanced undergraduate signal processing program due to the availability of eight academics at the SPRC with PhDs in the signal processing area.

2. THE PROGRAM STRUCTURE

The division of the three courses conducted at QUT into specialisation streams enabled us to include four core signal processing units in the signal processing program. In the third year the students are able to choose between two streams - the telecommunications and signal processing stream or the power systems stream. In the fourth year, electives are offered which allow the students to choose from signal processing, telecommunications, power systems, electromagnetics, electronics, computing or control systems, and therefore, further specialize in signal processing if they wish to.

The units comprising the signal processing program are:
Signals and Linear Systems – 3rd year - 1st semester.
Digital Signal Processing – 3rd year - 2nd semester.
Modern Signal Processing – 4th year - 1st semester .
Signal Computing and Real Time DSP – 4th year - offered both semesters.
Digital Spectral Analysis – 4th year - 2nd semester.

The aims of the units are as follows: The aim of the first unit, Signals and Linear Systems, is to introduce mathematical techniques such as Fourier analysis, continuous and discrete time system theory and random processes, as well as lay the foundation for a study of digital signal processing. The second unit Digital Signal Processing covers in depth techniques such as digital filtering and fast Fourier transforms. The third unit Modern Signal Processing covers statistical aspects of signal processing such as random variables, random processes, spectral analysis, detection and estimation theory.

The first three units mentioned above have a strong mathematical content providing plenty of intuition about the mathematical properties of algorithms. The fourth unit named Signal Computing and Real Time Digital Signal Processing has been added to cover applications and implementation issues. The aims of this unit are to complement the theory with computer based experiments and demonstrate the concepts of signal processing through applications. The unit is intensively laboratory based. A new laboratory has been specifically developed for this unit to provide a "hands-on" approach to the teaching of signal processing techniques. The motivation for the development of this laboratory was the cliché "What I hear, I remember, but what I do, I understand". The laboratory provides practical training to approximately 150 final year undergraduate students each year.

The elective unit Digital Spectral Analysis has been specially designed to prepare high calibre undergraduate students to undertake research in the area of signal processing. The unit has a unique blend of theory and applications of signal processing. It introduces problem solving techniques such as signal and system modelling and system simulation for analysis and design. It also discusses detection and estimation problems. The unit takes a unified approach dealing with practical problems in such diverse areas as radar, mobile communications and computer vision because it is intended to prepare students for research in one of the three laboratories of the centre - the Signal Research Laboratory, the Speech Research Laboratory or the Image Research Laboratory. Students then choose to concentrate in areas such as computer vision, speech technology, robotics, radar, telecommunications and information theory.

3. THE UNDERGRADUATE SIGNAL PROCESSING LABORATORY

A new undergraduate signal processing laboratory has been established to support the unit Signal Computing and Real-Time DSP by setting up a number of DSP experiments using Pentium based work stations. The laboratory also serves to complement the formal coursework by providing a "hands-on" approach to signal processing. One of the unique features of this laboratory is that the basic Digital Signal Processing techniques are illustrated using real world signals such as speech and images. The most important concepts of signal processing are reinforced through implementations and applications. The experiments that the students perform have been developed with the specific aim of encouraging a deeper understanding of the concepts of signal processing material with the simultaneous hightening of the interest of the students. The experiments also help the students to learn some of the impacts of practical engineering issues on system design. They also expose the students to specific engineering software tools (eg: Matlab) and hardware tools (the TMS320 development system) commonly used in industry. The unit thus enables the students to gain the necessary background skills and experience to become marketable.

3.1 Division into Modules

The unit, "Signal Computing and Real-Time DSP", is divided into 4 modules and each module has a number of experiments which are performed in the laboratory. Each module consists of five lectures each of 90 minutes duration. The modules introduce a set of related concepts and serve to fill in theoretical concepts that were not covered by the previous three signal processing units.

Signal Theory Module: This module is aimed at developing a deeper insight into signal processing concepts. The concepts of convolution, correlation, IIR and FIR digital filters, Fast Fourier transforms, spectral analysis, etc., are reinforced using two PC based packages: Matlab and Hypersignal.

Speech Processing Module: Experiments in this module are performed using Hypersignal and Matlab with speech acquisition and play back facilities. The students learn basic speech processing techniques and their applications to speech coding, speech recognition, speaker verification and speaker identification.

Image Processing Module: Experiments in this module are performed using Hypersignal Block diagram and Matlab with the image toolbox. The experiments include point processes and histograms, image enhancement, edge detection, morphological operations, contour extraction and image compression techniques.

Real-time DSP Module: This module is based on the TMS320C30 EVM board on a PC equipped with C compiler, assembler, linker, and simulator. The students learn how to implement real time DSP systems.

3.2 Software for Laboratory Exercises

Two signal processing software packages have been chosen for the experiments in the laboratory: Hypersignal and Matlab. Hypersignal Block Diagram is a window based visually programmed object oriented simulation package. By arranging the icons, signal processing algorithms can be designed and tested. The icons represent input functions, processing functions, output functions and display functions. The most interesting aspect of Hypersignal which makes it an ideal teaching aid is that students can create their own functions using a C-compiler. The block diagram approach enables students to quickly build signal processing systems and test them using input signals and also interactively change and analyse and graphically observe the results. Hypersignal provides a number of standard library blocks such as FFT, convolution, etc.

As a part of their assignments the students have built additional blocks to extend this library. Several of the new blocks can be used by other students to build various signal processing tasks. The blocks that have been designed by students include: (1) Adaptive filter block using Widrow's Least Means Squares algorithm, (2) Discrete Cosine Transform Block, and (3) Discrete Hartley Transform Block. Feedback from the students indicates that the block oriented approach of implementing and analysing signal processing functions improves their understanding of basic signal processing concepts and helps them to remember the relevant signal processing techniques.

The second software package that is used in the laboratory is Matlab which is already in widespread use in both academia and industry. We have used Matlab mainly as a problem solving tool. Matlab serves as an effective and efficient platform for the students to develop problem solving skills. The students are provided with a number of problems in linear systems theory and are then asked to solve these using Matlab. Many of these problems can be solved with pencil and paper but the advantages of Matlab are its high speed mathematical calculations, high speed interactive graphics and simple programmability.

A set of problem based and computer assisted learning items for image processing has also been developed for use with the image processing module. These items introduce image processing concepts with real world problems as starting points as opposed to traditional lecture based methods of teaching and learning.

3.3 Real-Time Processing

This module is introduced to enable students to gain "hands on" experience with modern DSP devices. The Texas Instruments TMS320C30 has been selected as it represents the state of the art in floating point DSP technology. The laboratory work in this module begins with familiarizing the students with the TMS320C30 EVM hardware and software they would be using. This is accomplished with a series of five experiments of increasing difficulty that the students complete in their own time. The C30 code for each experiment is provided to the students. Each experiment is assessed on the basis of a brief demonstration and interview. All familiarization experiments are made compulsory.

3.4 Mini Projects

After doing the five real-time experiments, the students are asked to write their own real-time programs. They are split into groups of two or three and given the choice of a number of different programming assignments. Typical mini projects that are given include real time implementation of A Cepstral Processor, Speech Time Warping, DCT Speech Scrambler, Digital Oscilloscope/Spectrum Analyser, Isolated Word Speech Recogniser, and Vocal Tract Area Function Display. The response to these assignments is very encouraging. The students enjoy seeing their programs in action - a usually dynamic end result of their labours. A great deal of lateral and inventive approaches have been exhibited in the solutions to the problems, exploring both the algorithmic techniques as well as real time programming techniques.

4. PREPARATION FOR POSTGRADUATE STUDIES

The SPRC offers Master of Engineering (by research) and Master of Engineering Science (coursework) degrees as well as a Ph.D. in Electrical Engineering. The centre has three well-equipped laboratories for research in Signal theory, Speech processing and Image processing, respectively. The undergraduate units have been structured to prepare and motivate capable students for postgraduate study in one of these areas. The last core unit of the signal processing stream within the undergraduate course, Signal Computing and Real-time Digital Signal Processing, is therefore, designed to expose students to speech processing and image processing. In addition, the elective unit, Digital Spectral Analysis, prepares students for research into radar, array processing, nonstationary and nonGaussian signal processing, time-frequency analysis, multiscale techniques, higher order statistics, etc.

Most of the training of the postgraduate students occurs while working in one of the three laboratories at the centre under the supervision of academics from the centre. The laboratories also provide an excellent arena for technical discussions between students who are working on related topics. The centre, thus arranges, the external conditions required for self-directed study, learning experiences and group interaction. State-of-the-art hardware and software for data acquisition, computing, word processing, plotting and printing are available in each laboratory. The undergraduate courses also have design and project units at the third and fourth year levels. Academics from the Signal Processing Research Centre supervise signal processing projects by undergraduate students. Some of these projects are linked to ongoing research projects and serve as stepping stones to postgraduate research.

Formal postgraduate units of study are also offered dependent upon lecturer availability and student needs. These include Advanced Digital Signal Processing, Error Control and Data Compression Techniques, Multiscale Signal Processing, Multidimensional Signal Processing, Communications Digital Signal Processing, Detection and Estimation Theory, Image Processing and Computer Vision. The emphasis in postgraduate coursework is on the availability of a wide variety of electives to suit the needs of ongoing research projects as they arise, and on the design of new units to cover new developments in technology and emerging areas in research. The undergraduate program on the other hand includes sufficient core content in the form of four units to support these electives.

5. CONLUSIONS AND PERSPECTIVES

This paper shows how an advanced signal processing program may be successfully incorporated into an undergraduate degree course. The approach presented provides a structured introduction to signal processing theory through four core units and one elective and to its practice by one laboratory based unit. A research centre in signal processing, the Signal Processing Research Centre, helps with design and project components of the undergraduate course with regard to signal processing, and with training opportunities for postgraduate studies and research.

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